

APPENDIX C

DISCUSSION OF OKLAHOMA CITY MEASUREMENTS

C.1 INTRODUCTION

This section discusses measurements conducted at the FAA Academy in Oklahoma City, Oklahoma. The objective of these measurements were to:

- 1) Determine what emission limits are necessary to protect selected Federal radio systems, and
- 2) Validate the one-on-one interference analysis procedure by determining the minimum distance separation and/or the maximum UWB EIRP to ensure compatibility between UWB devices and selected Federal radionavigation and safety-of-life systems.

Measurements were conducted on three National Airspace Systems equipment: ARSR, ASR, and the ATCRBS. Prior to conducting radiated measurements, preliminary closed system measurements were conducted to determine the receiver noise level and to observe the UWB signal characteristics at the receiver IF output for various UWB signal levels.

C.2 RADIATED MEASUREMENTS

All radiated measurements were conducted with the radar antenna not rotating and pointing at the NTIA Radio Spectrum Measurement System (RSMS) van. The horn antenna on the RSMS van was mounted on the top of the van at a height of 4 meters and pointed at the radar. The RSMS van equipment was set-up as shown in Figure C-1 with the attenuator set to produce an EIRP of -41 dBm, log-average using the video filtering technique (1 MHz RBW, 10 Hz VBW) for each UWB signal radiated.

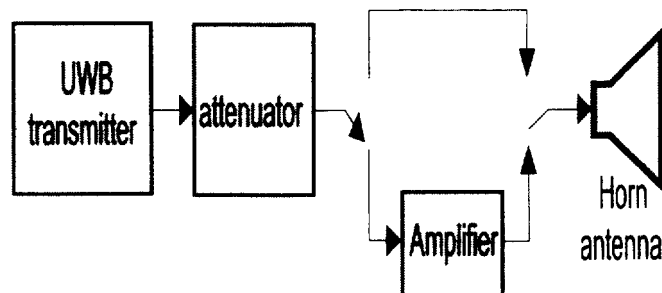


Figure C-1. UWB Pulsar Equipment Configuration.

C.2.1 Air Route Surveillance Radar (ARSR-4)

The following is a summary of the radiated measurements conducted on the ARSR-4.

Receiver Characteristics:

1. IF bandwidth = 1.3 MHz (measured)
2. IF Frequency at J3 = 36.25 MHz (measured)
3. Receiver input noise level = -113 dBm (calculation)
4. Receiver noise level at IF output (J3) = -79 dBm (measured)
5. Antenna low beam gain = 41.86 dBi. (obtained from manual)
6. Antenna height = 100 feet (30.48 meters)
7. Receiver front end losses (L_R), = 0.5 dB (estimated)

Radar Measurement Setup:

1. Receiver Channel A (1241.47 MHz)
2. Monitored Channel 1 (low beam, array rows 6-9) IF output (J3)
3. UWB Signal injected at row 8 of the antenna feed array prior to LNA and before channel beam forming network (cable loss to injection point (L_c) = 26 dB)
4. Transmitter off
5. Test targets off
6. Sensitivity Time Control (STC) set to 5 nm (minimum)
7. AGC frozen (maintains constant AGC during tests. Noise level is sampled during dead time and AGC established based on system noise)
8. Antenna low beam -2.5 dB point set on the horizon (G_r = 38.36 dBi)
9. Location (lat. 35°, 24', 12.8" N /lon. 97°, 37', 44.2" W)

Note: Limited measurements were made observing the affects of CW-like interference to the ARSR-4 radar. It was determined that CW-like interfering signals reduce the receiver gain. A 10 MHz non-dithered signal produced a CW-like signal at the receiver IF output.

Site Selection: Measurement sites were selected by observations from the radar antenna platform and by measuring the signal from the ARSR-4 using the receiver in the RSMS van. The variation in coupling between an FAA ARSR-4 radar at the Oklahoma City Technical Center and a UWB antenna on the RSMS van is shown over a distance of 0.4 to 3.6 kilometers (see Figure C-2). This figure was generated by driving the NTIA RSMS van slowly away from the radar while measuring the power coupled from the radar. The beam rotated past the van every 10 seconds, resulting in the periodic spikes seen in the figure. For the particular measurement shown in Figure 1, the maximum coupling level occurs at 1.25 kilometers, and gradual drop-off in coupling beyond that distance. Similar measurements were performed for ASR-8, and ATCBI-5 antennas at Oklahoma City.

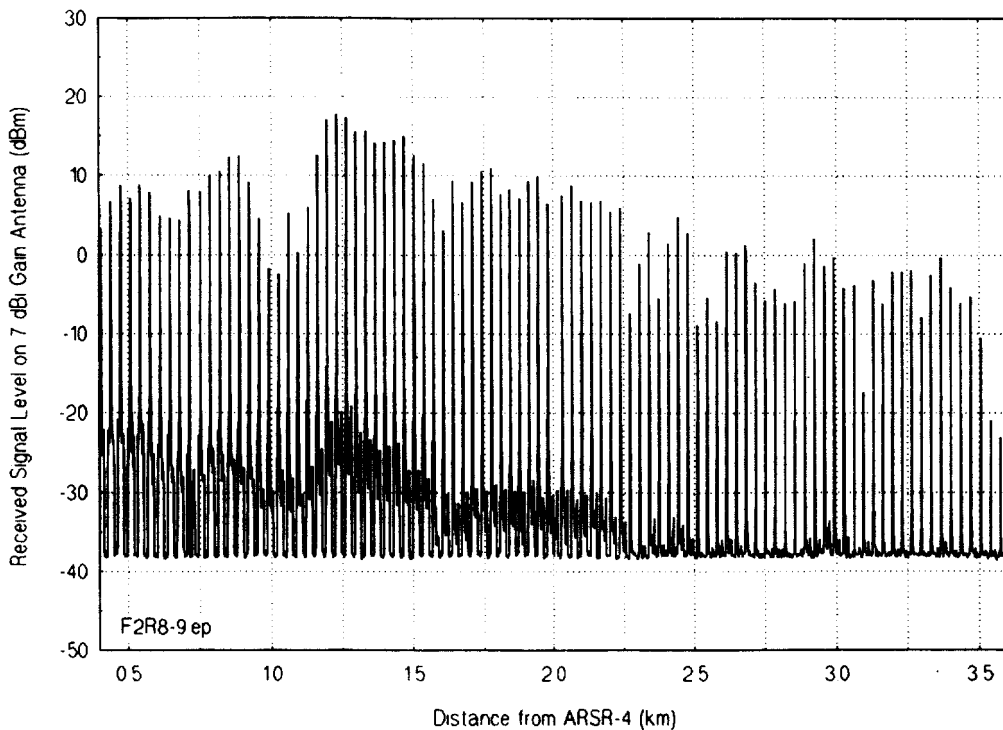


Figure C-2. Received Signal Level as a Function of Distance from the ARSR-4 Radar.

Site Measurements: At each selected measurement site, the distance was measured using a GPS receiver. The following is a summary of the measurement data for each measurement site.

Site #1: The RSMS van was located on Halaby Drive at the TDWR site (Lat. $35^{\circ} 23' 31.8''$ /Lon. $97^{\circ} 37' 41.4''$). The site was 1.26 km from the ARSR-4 and a bearing of 179.5° on the ARSR-4 bearing indicator. The measured $(I+N)/N$ ratio at the ARSR-4 receiver IF output were:

The 10 MHz PRF dithered UWB signal produced an $(I+N)/N$ ratio of 9 dB. An $(I+N)/N$ ratio of 9 dB equates to an I/N ratio of 8.4 dB. The measurements showed that it was necessary to attenuate the UWB signal by 15 dB to limit the $(I+N)/N$ ratio to 1 dB, $I/N = -6$ dB. For a protection criteria of $I/N = -10$ dB, it would be necessary to limit the emission from UWB devices to 18.4 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -56.9 dBm RMS (-38.5 dBm RMS -18.4 dB).

Site #2: The RSMS van was located on Rockwell Avenue (Lat. $35^{\circ} 23' 09''$ /Lon. $97^{\circ} 38' 10.2''$). The site was 2.1 km from the ARSR-4 and a bearing of 203° on the ARSR-4 bearing indicator. The measured $(I+N)/N$ ratio at the ARSR-4 receiver IF output were:

The 10 MHz PRF dithered UWB signal produced an $(I+N)/N$ ratio of 11 dB. An $(I+N)/N$ ratio of 11 dB equates to an I/N ratio of 10.6 dB. The measurements showed it was necessary to attenuate the UWB signal by 18 dB to limit the $(I+N)/N$ ratio to 1 dB, $I/N = -6$ dB. Figures C-3 and C-4 show the ARSR-4 IF output for the baseline noise level (UWB signal off) and with the UWB signal on for peak detector (RBW and VBW = 1 MHz), and the average signal level using video filtering (RBW = 1 MHz and VBW = 10 Hz), respectively. For a protection criteria of $I/N = -10$ dB, it would be necessary to limit the emission from UWB devices to 20.6 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -59.1 dBm RMS (-38.5 dBm RMS -20.6 dB).

Site #3: The RSMS van was located on North Meridian Avenue just south of Airport Road and north of the grave yard (Lat. $35^{\circ} 25' 14.4''$ /Lon. $97^{\circ} 36' 3.1''$). The site was 3.1 km from the ARSR-4 and a bearing of 56° on the ARSR-4 bearing indicator. The measured $(I+N)/N$ ratio at the ARSR-4 receiver IF output were:

The 10 MHz PRF dithered UWB signal produced an $(I+N)/N$ ratio of 8 dB. An $(I+N)/N$ ratio of 8 dB equates to an I/N ratio of 7.2 dB. For a protection criteria of $I/N = -10$ dB, it would be necessary to limit the emission from UWB devices to 17.2 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -55.7 dBm RMS (-38.5 dBm RMS -17.2 dB).

Incidental Radiator Measurements: At each of the measurement sites an electric drill and razor were radiated to see if they could be observed at the ARSR-4 IF output. The electric drill was not detected at any on the measurement sites. The electric razor was observed to produce asynchronous spikes 10-15 dB above system noise at Site #1. However, the average (RMS) noise level at the IF output was observed and there was no increase in the average (RMS) noise level at the IF output due to the electric razor.

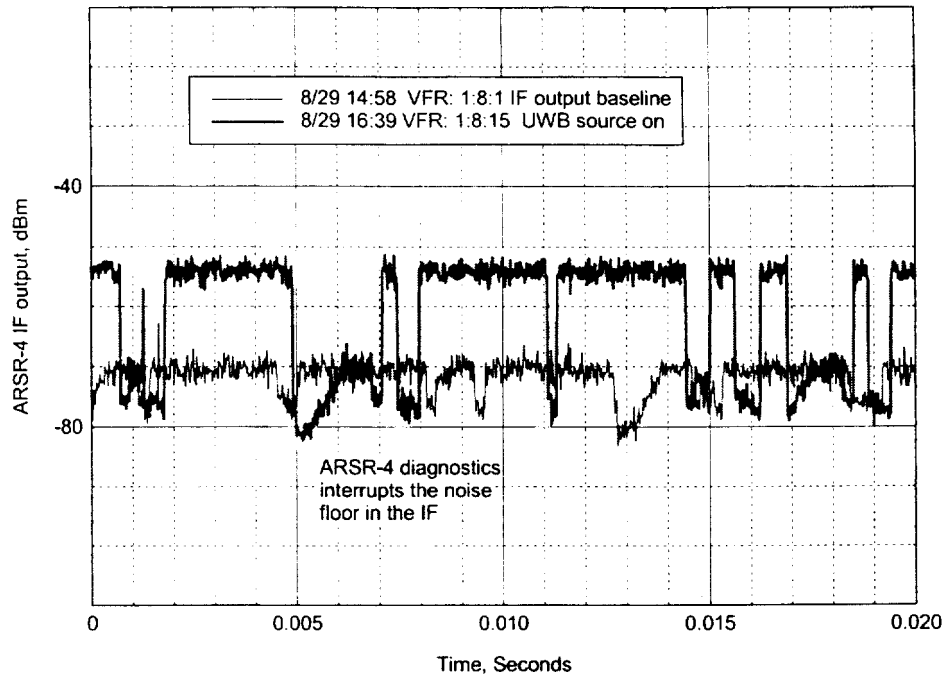


Figure C-3. ARSR-4 IF Output for Baseline Noise Level (UWB Signal off) and UWB Signal on for Site #2 (2.1 km). Peak Detected in 1 MHz Resolution and Video Bandwidth.

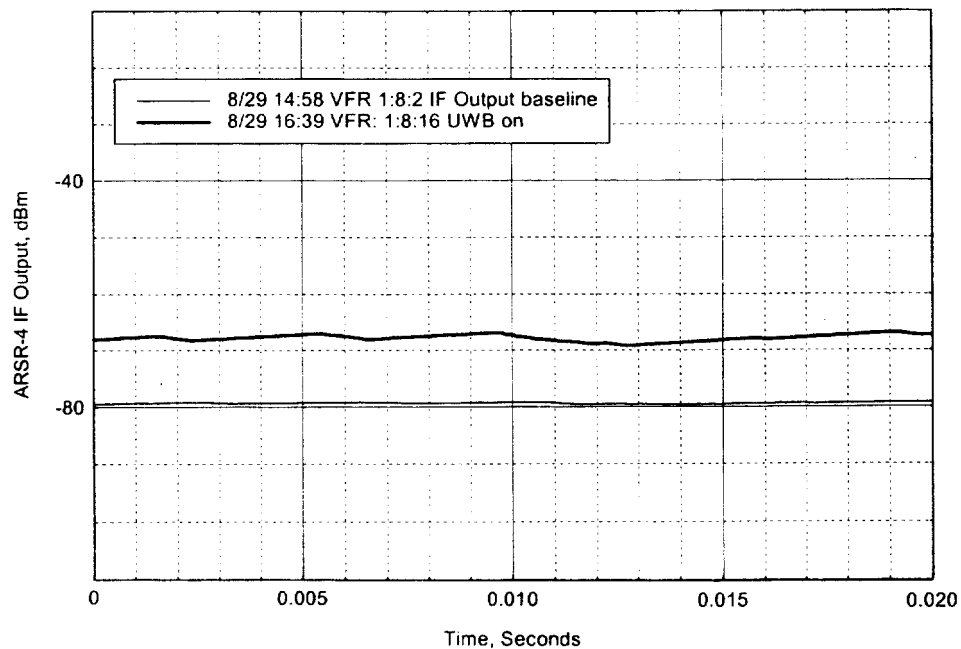


Figure C-4. ARSR-4 IF Output for Baseline Noise Level (UWB signal off) and UWB Signal on for Site # 2 (2.1 km). Peak Detected in 1 MHz Resolution Bandwidth and 10 Hz Video Bandwidth.

C.2.2 Airport Surveillance Radar (ASR-8)

The following is a summary of the closed system and radiated measurements conducted on the ASR-8.

Receiver Characteristics:

1. IF bandwidth = 0.9 MHz (measured)
2. IF Frequency at = 30 MHz (measured)
3. Receiver input noise level = -110 dBm (measured)
4. Receiver noise level at normal channel IF output (TP-9) = -11 dBm (measured)
5. Receiver normal channel saturation level = -80 dBm (measured)
6. Antenna low beam gain = 34 dBi. (obtained from manual)
7. Antenna height = 45 feet (13.71 meters)
8. Antenna tilt angle = 1.5 degrees
9. Receiver front end losses (L_R), = 2.0 dB (estimated)

Radar Measurement Setup:

1. Receiver Channel A (2770 MHz)
2. Monitored normal channel IF output (TP-9)
3. UWB signal injected into low beam (active channel) waveguide. The coupler loss (L_c) = 20 dB (coupler label)
4. Transmitter off
5. Exciter test targets off
6. STC off
7. AGC set to normal
8. Antenna gain on the horizon = 27 dBi (approximate)
9. Location (lat. 35°, 24', 5.2" N /lon. 97°, 37', 17.9", W)

Radiated Measurements:

Site Selection: Measurement sites were selected by observations from the radar antenna platform and by measuring the signal from the ASR-8 using the receiver in the RSMS van. The RSMS van was set up to measure the signal from the ASR-8, and driven in areas around the above estimated distance separations to determined locations where maximum signal levels from the ASR-8 were received. This information was used to select measurement sites to perform radiated measurements using the UWB pulser signal generator. At each selected measurement site the distance was measured using a GPS receiver.

Site Measurements: The radiated measurements were conducted with the radar antenna not rotating, and the antenna pointing at the RSMS van. The RSMS van equipment was set-up as shown in Figure 3, and the attenuator set to produce an EIRP of -41 dBm log-average using the video filtering technique (1 MHz RBW, 10 Hz VBW) for each UWB

signal radiated. The following is a summary of the measurement data for each measurement site.

Site #1: The RSMS van was located on Foster Drive (Lat. $35^{\circ} 24' 14.2''$ /Lon. $97^{\circ} 37' 26.8''$). The site was 0.4 km from the ASR-8 and a bearing of 317° on the ASR-8 bearing indicator. The measured UWB signal levels at the ASR-8 receiver IF output were:

- A. The 10 MHz PRF dithered UWB signal produced an $(I+N)/N$ ratio of 3.7 dB. An $(I+N)/N$ ratio of 3.7 dB equates to an I/N ratio of 1.2 dB. For a protection criteria of $I/N = -10$ dB, it would be necessary to limit the emission from UWB devices to 11.2 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -49.7 dBm RMS (-38.5 dBm RMS -11.2 dB).
- B. The 10 MHz PRF non-dithered UWB signal produced an $(I+N)/N$ ratio of 4.4 dB. An $(I+N)/N$ ratio of 4.4 dB equates to an I/N ratio of 2.4 dB. Figures C-5 and C-6 show the ASR-8 IF output for the baseline noise level (UWB signal off) and with the UWB signal on for peak detector (RBW and VBW = 1 MHz), and the average signal level using video filtering (RBW = 1 MHz and VBW = 10 Hz), respectively. For a protection criteria of $I/N = -10$ dB, it would be necessary to limit the emission from UWB devices to 12.4 dB below the EIRP level (-41 dBm RMS -12.4 = -53.4 dBm RMS).

Site #2: The RSMS van was located on MacArthur Boulevard (Lat. $35^{\circ} 24' 48.5''$ /Lon. $97^{\circ} 37' 6.9''$). The site was 1.4 km from the ASR-8 at a bearing of 11.5° on the ASR-8 bearing indicator. The measured UWB signal levels at the ASR-8 receiver IF output were:

- A. The 10 MHz PRF dithered UWB signal produced an $(I+N)/N$ ratio of 1.7 dB. An $(I+N)/N$ ratio of 1.7 dB equates to an I/N ratio of -3.1 dB. For a protection criteria of $I/N = -10$ dB, it would be necessary to limit the emission from UWB devices to 6.9 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -45.4 dBm RMS (-38.5 dBm RMS -6.9 dB).
- B. The 10 MHz PRF non-dithered UWB signal produced an $(I+N)/N$ ratio of 2 dB. An $(I+N)/N$ ratio of 2 dB equates to an I/N ratio of -2.3 dB. For a protection criteria of $I/N = -10$ dB, it would be necessary to limit the emission from UWB devices to 7.7 dB below the EIRP level (-41 dBm RMS - 7.7 dB = -48.7 dBm RMS).

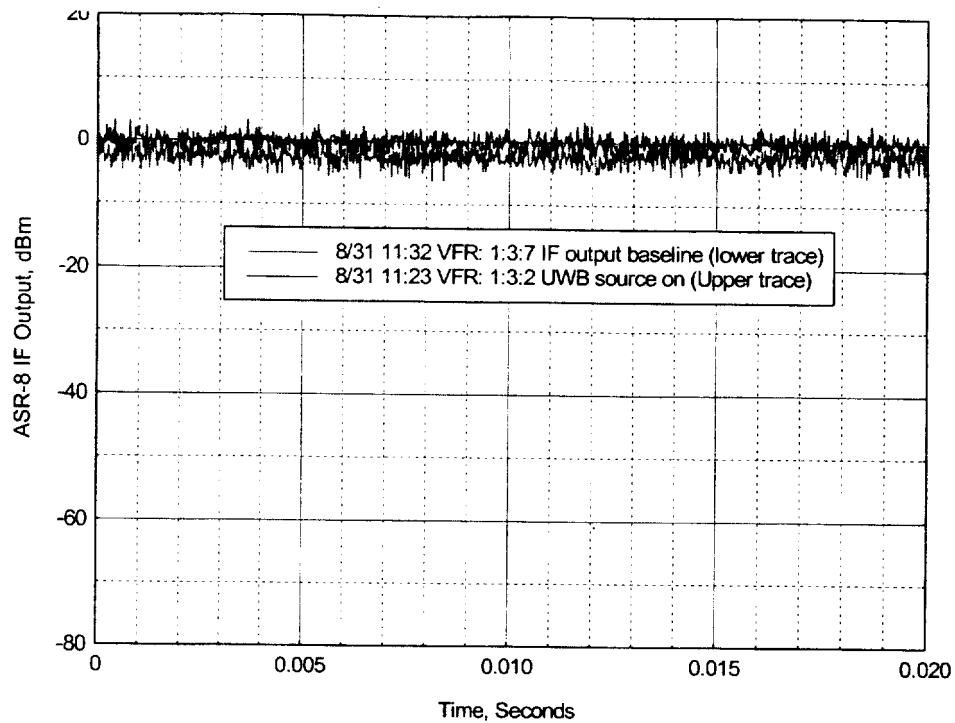


Figure C-5. ASR-8 IF output for baseline noise level (UWB signal off) and UWB signal on for Site #1 (0.4 km). Peak detected in 1 MHz resolution and video bandwidth.

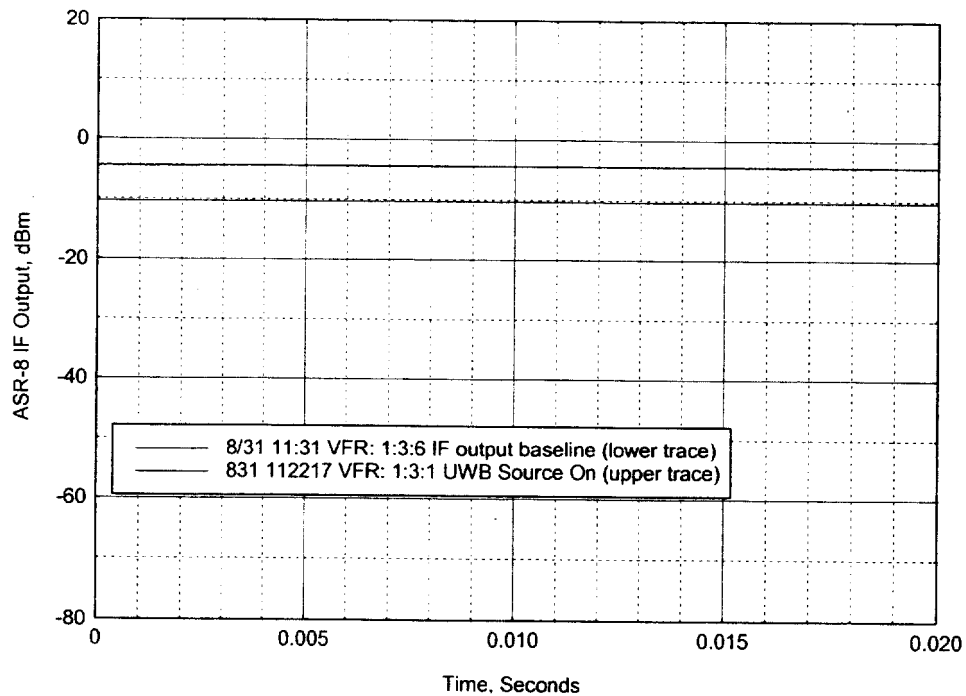


Figure C-6. ASR-8 IF Output for Baseline Noise Level (UWB Signal Off) and UWB Signal on for Site #1 (0.4 km). Peak Detected with 1 MHz Resolution Bandwidth and 10 Hz Video Bandwidth, RMS Noise Level.

Incidental Radiator Measurements: At each of the measurement sites an electric drill, electric razor and hair dryer were radiated to see if they could be observed at the ASR-8 IF output. None of the incidental radiators were observed at the radar IF output from Site 1 or 2.

C.2.3 ATCBI-5

The following is a summary of the closed system and radiated measurements conducted on the ATCBI-5 beacon associated with the ARSR-4. It should be noted that these measurement results may not be representative of an ATCBI-5 beacon associated with ASRs since the antenna is a different type.

Receiver Characteristics:

1. IF bandwidth = 8.9 MHz (measured)
2. IF Frequency at TP1 = 60 MHz (measured)
3. Receiver input noise level = -102 dBm (calculated)
4. Receiver noise level at IF output (TP1) = -64.5 dBm (measured)
5. Antenna main beam gain = 26 dBi (obtained from manual)
6. Antenna main beam gain on the horizon = 23 dBi (obtained from manual)
7. Antenna height = 100 feet (30.48 meters)
8. Receiver front end losses (L_R), = 2.0 dB (estimated)

Radar Measurement Setup:

1. Receiver Channels A and B(1090 MHz)
2. Monitored IF output (TP1)
3. UWB Signal injected at receiver input coupler through a filter (coupler loss (L_c) = 30 dB)
4. Transmitter output dumped into a dummy load to stop interrogations
5. Adjustment made to minimize off time (dead time)
8. STC turned off
7. Location (lat. 35°, 24', 12.8" N /lon. 97°, 37', 44.2" W)

Note: Limited measurements were made observing the affects of CW-like interference to the ATCBI-5 radar. It was determined that CW-like interfering signals reduce the receiver gain. A 10 MHz non-dithered signal produced a CW-like signal at the receiver IF output.

Radiated Measurements:

Site #1: The RSMS van was located on Halaby Drive at the TDWR site (Lat.35° 23' 31.8"/Lon.97° 37' 41.4"). The site was 1.26 km from the ATCBI-5 and a bearing of [179.5°] on the ATCBI-5 bearing indicator. The UWB signal was not observed at the ATCBI-5 IF output for either the UWB dithered or undithered signal.

Site #2: The RSMS van was located on Halaby Drive at (Lat.35° 23' 56.8"/Lon.97° 37' 42.7"). The site was 0.5 km from the ATCBI-5, and at a bearing of 181° on the ARSR-4 bearing indicator. The measured UWB signal levels at the ATCBI-5 receiver IF output were:

- A. The 10 MHz PRF dithered UWB signal was not observed at the receiver IF output.
- B. The 10 MHz PRF non-dithered UWB signal produced an (I+N)/N ratio of 0.7 dB. An (I+N)/N ratio of 0.7 dB equates to an I/N ratio of -7.6 dB. For a protection criteria of I/N = -10 dB, it would be necessary to limit the emission from UWB devices to 2.4 dB below the FCC Part 15 limit (-43.7 dBm).

Incidental Radiator Measurements: At each of the measurement sites and an additional site, 50 ft. on the ground from the antenna tower, an electric drill and razor were radiated to see if they could be observed at the ATCBI-5 IF output. The electric drill and razor were not detected at any of the measurement sites.

C.3 SUMMARY OF FINDINGS

The following is a summary of the findings from measurements conducted at Oklahoma City, OK. Since the measurements were conducted at a limited number of measurement sites (distances from the radars), specific radar system configurations (antenna height and tilt angle), UWB antenna height and specific local terrain environment, the findings given below should not be taken as representative conditions that will ensure protection of the radar systems.

1. The measurements indicate that the potential for interference to ARSRs and ASRs from UWB devices can occur in an annular ring around each radar. The distance to the angular ring and the diameter of the angular ring depends on the antenna height, antenna pattern and the antenna vertical tilt angle. The antenna gain elevation pattern is key in performing an EMC analysis.
2. The measurements made on the ASR-8 radar may not be representative of the potential for interference to the new generation Doppler type radars (ASR-9 and ASR-11). The Doppler radars, which process out ground clutters, may have higher antenna gain levels on the horizon. It was noted that the ASR-8 had an antenna vertical tilt angle of +1.5° and the ASR-9 had an antenna vertical tilt angle of only +0.5°.
3. The ATCBI-5 measurements were conducted on the enroute radar ARSR-4. The ATCBI-5 antenna on the ARSR-4 may have different elevation gain characteristics than the ATCBI-5 antennas on the ASRs. Also, the antenna heights of the ASRs may be lower than the ARSRs. Therefore, the measurements on the ATCBI-5 assessing the potential for interference from UWB devices may not be worst case.

4. The ATCBI-5 radar has a 10 dB higher noise level and lower antenna gain than the ARSR-4 and ASR-8 radars. Therefore, the UWB signal levels only exceeded the protection criteria of -10 dB by one dB.
5. Measurements conducted on the ARSR-4 and ATCBI-5 showed that CW-like interference can cause a reduction in the receiver gain. Therefore, in addition to an increase in the receiver noise floor, the desired target levels may be affected. This degradation mechanism was not investigated.
7. Measurements on the potential for interference from incidental radiator devices (electric drill, electric razor and hair drier) to the ARSR-4, ASR-8 and ATCBI-5 showed that only the electric razor could be observed above the ARSR-4 system noise level at the IF output. However, the receiver noise level at the IF output was observed and there was no increase in the noise level at the IF output due to the electric razor. Therefore, the measurements indicate that the RMS emission level of the electric razor is significantly less than the RMS emission levels of the UWB characteristics used in the measurements.

APPENDIX D

PEAK POWER IN A 50 MHz BANDWIDTH

D.1 INTRODUCTION

The following is a discussion of the peak power of a UWB signal in a receiver 50 MHz IF bandwidth to average (RMS) power in a 1 MHz reference bandwidth. The FCC proposed in the UWB NPRM that the peak power limit be based on a 50 MHz bandwidth.¹⁰⁷ The receiver transfer properties for both non-dithered and dithered UWB signals in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth as a function of the UWB signal PRF are provided. It is assumed that the UWB device emission bandwidth is greater than 50 MHz and uniform across the receiver bandwidth. Also, the calculations do not include any additional peak power factor for gated UWB signals.

The following equations given below were developed based on measurements and simulations contained in the ITS Report.¹⁰⁸

D.2 PEAK POWER BWCF TRANSFER PROPERTIES FOR NON-DITHERED UWB SIGNALS

For non-dithered UWB signals, the peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz can be calculated using Equations 3-9 through 3-12 in Section 3 of this report. The peak power BWCF equations for non-dithered UWB signals are provided below.

For $B_{IF} \leq 0.45 \text{ PRF}$, the peak power $BWCF_p$ can be expressed as:

$$BWCF_p = 0, \quad \text{for } B_{IF} \leq 0.45 \text{ PRF} \quad \text{and } B_{Ref} < \text{PRF} \quad (D-1)$$

$$BWCF_p = 10\log(\text{PRF}/B_{Ref}), \quad \text{for } B_{IF} \leq 0.45 \text{ PRF} \quad \text{and } B_{Ref} \geq \text{PRF} \quad (D-2)$$

For $B_{IF} > 0.45 \text{ PRF}$, the peak power $BWCF_p$ can be expressed as:

$$BWCF_p = 20\log_{10}(B_{IF}/0.45 \times \text{PRF}), \quad \text{for } 0.45 \text{ PRF} \leq B_{IF} < 1/T \quad \text{and } B_{Ref} < \text{PRF} \quad (D-3)$$

$$BWCF_p = 10\log_{10}[B_{IF}^2/(0.2 \times B_{Ref} \times \text{PRF})], \quad \text{for } 0.45 \text{ PRF} \leq B_{IF} < 1/T \quad \text{and } B_{Ref} \geq \text{PRF} \quad (D-4)$$

¹⁰⁷ See UWB NPRM, *supra* note 2, at ¶ 42.

¹⁰⁸ See ITS Report, *supra* note 14, at Section 8, Appendix B and D.

D.3. PEAK POWER BWCF TRANSFER PROPERTIES FOR DITHERED UWB SIGNALS

The analytical approach used in the UWB analysis report considers that when the UWB time waveform response at the receiver IF output is noise-like an average signal power level is used in assessing receiver performance degradation. Therefore, for dithered UWB signals, the BWCF equations in Section 3 for peak power are not directly applicable for determining the peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth. Recognizing that for Gaussian noise, the peak to average (RMS) power ratio is 10 dB.

For $B_{IF} \leq 2.0$ PRF, the peak power $BWCF_P$ can be expressed as:

$$BWCF_P = 10 + 10\log_{10}(B_{IF}/B_{Ref}), \quad \text{for } B_{IF} \leq 2.0 \text{ PRF} < 1/T \quad (D-5)$$

and $B_{Ref} = \text{Any value}$

For $B_{IF} > 2.0$ PRF, the peak power $BWCF_P$ can be expressed as:

$$BWCF_P = 10\log_{10}[B_{IF}^2/(0.2 \times B_{Ref} \times \text{PRF})], \quad \text{for } B_{IF} > 2.0 \text{ PRF} < 1/T \quad (D-6)$$

and $B_{Ref} = \text{any value}$

NOTE: For the above equations, the receiver IF bandwidth (B_{IF}), UWB signal PRF, and measurement reference bandwidth (B_{Ref}) values are in MHz.

D.4 SUMMARY DISCUSSION OF PEAK POWER IN A 50 MHz BANDWIDTH

Figure D-1 shows the peak power in a 50 MHz bandwidth ($B_{IF} = 50$) to the average (RMS) power in a 1 MHz bandwidth ($B_{Ref} = 1$) for both non-dithered and dithered UWB signals and a range of PRFs based on the above equations. The FCC has proposed a 50 MHz reference bandwidth for establishing the peak power limit, and a 20 dB limit on the peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth.¹⁰⁹ From Figure D-1, for non-dithered UWB signals, a 20 dB peak power limit would restrict the UWB signal PRF to greater than 11.1 MHz. For dithered UWB signals, the lowest achievable peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth is 27 dB, and occurs for UWB signal PRFs equal to or greater than 25 MHz. Therefore, for dithered UWB signals, a 20 dB limit of peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth is not achievable. For a 30 dB peak limit, the PRF of non-dithered UWB devices would be limited to greater than 3.5 MHz, and the PRF of dithered UWB devices would be limited to greater than 12.5 MHz.

¹⁰⁹ The measurement procedure the FCC uses for average power for Part 15 compliance is an average logarithmic value. The analysis contained in this appendix uses an average (RMS) power level.

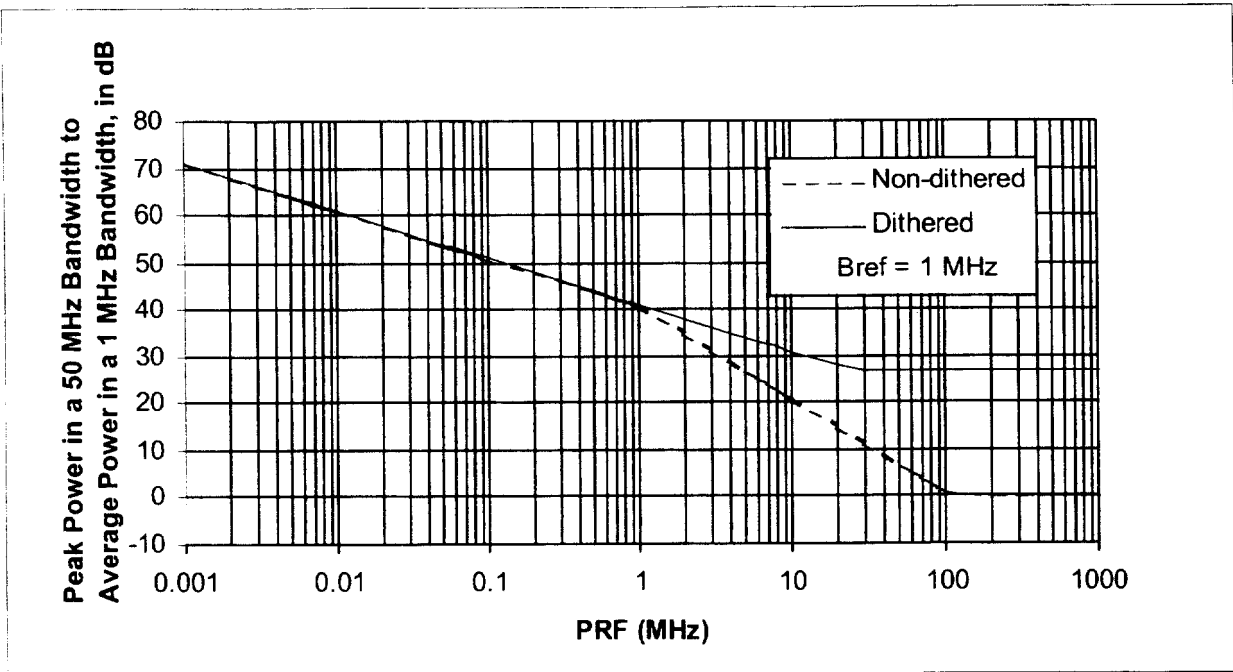


Figure D-1. Peak Power in a 50 MHz Bandwidth to Average (RMS) Power in a 1 MHz Bandwidth as a Function of UWB Signal PRF.

